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Procedia Engineering 14 (2011) 2872–2877

Procedia Engineering

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The Twelfth East Asia-Pacific Conference on Structural Engineering and Construction

Simplification of Earthquake Accelerograms for Quick Time History Analyses by using Their Modified Inverse Fourier Transforms

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Abstract

There are several cases in seismic design of structures in which the simplified seismic analysis of the code is not usable. In such cases most codes recommend time history analysis, which is very time-consuming, mainly since the time step size of the digitized accelerograms is usually very small. Therefore, if the time history analysis can be performed by large time steps without losing much precision, it can be very helpful. In this paper, a method is introduced for simplification of accelerograms based on the modification of their Fourier Analyses. For this purpose, at first the Fourier Spectrum of the accelerogram is calculated. Then, by using a computer program, developed by the authors, a modified version of Fourier Spectrum is produced, containing only the frequencies which are close to those few frequencies of the structural system that have higher modal participation factors. Finally, the corresponding Inverse Fourier Transform is calculated using a relatively large time step, depending on the period of the highest used frequency (which is usually 5 to 10 times larger than the original accelerogram's time step) to create the simplified accelerogram. Obviously, time history analysis by using this simplified accelerogram will be much less time-consuming. Numerical results show that the maximum response values obtained by using the simplified accelerograms have around 5 to 10 percent error depending on the type of the structure and the features of the used records.

Keywords: Dominant frequencies; Fourier and Inverse Fourier Transforms; Time step size.

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doi:10.1016/j.proeng.2011.07.361

1. INTRODUCTION

In seismic evaluation and design of structures including building systems, there are several cases in which the simplified seismic analysis procedures suggested by seismic design codes, are not usable. Irregular buildings, buildings with more than 15 stories (according to most of codes), and many special structures are some of these cases. In such cases most codes recommend time history analysis (THA) as the most appropriate analysis procedure. However, THA is usually very time-consuming and therefore costly, basically, because of the very small size of the time step used in digitization of accelerograms. On this basis, if the time history analysis can be performed by relatively larger time steps, without losing much precision, it will be very helpful. Creating the possibility of using larger time steps, by some techniques, is one of the approaches proposed for this purpose (Soroushian 2008). Using simplified accelerograms is another approach for this purpose (Wang 1975, Wang & Goel 1977). In these two works the real accelerogram has been condensed into a four-pulse model by a minimization method, using rectangular pulses. Simplification of digitized accelerograms, however, can be done by other means such as Fourier and Inverse Fourier Transforms, so that the simplified accelerogram can have larger time steps.

In this paper a method is introduced for simplification of accelerograms based on the modification of their Fourier Analyses. For this purpose, at first its Fourier Spectrum of the accelerogram is calculated, by a computer program, developed by the authors. Then, by using the developed computer program a modified Fourier Spectrum is produced, which contains only those frequencies which are close to the few frequencies of the structural system that have higher modal participation factors in its seismic response. Finally, the corresponding Inverse Fourier Transform is calculated, by the developed computer, using a relatively large time step, depending on the period of the highest used frequency (which is usually 5 to 10 times larger than the original accelerogram's time step) to create the simplified accelerogram. The details of this technique are described in the following section of the paper, and its efficiency in reducing the required time for THA is shown by some numerical examples.

2. ACCELEROGRAM SIMPLIFICATION TECHNIQUE AND SAMPLE RESULTS

As mentioned in the previous section, the simplification technique is based on modifying the Fourier Transform of the original digitized accelerogram and then calculating its Inverse Fourier Transform using time step size much larger than that of the original digitized accelerogram. For performing this modification, a computer program has been developed by the authors, which is compatible with MicroSoft Office program. In this computer program at first the Fourier Transform of the ground acceleration time history, $a_g(t)$, is calculated by:

$$F(\omega) = \int_0^{\tau_0} a_g(t) e^{-i\omega t} dt \tag{1}$$

where τ_0 is the duration of the accelerogram. Regarding that $F(\omega)$ has a real part and an imaginary part as:

$$C(\omega) = \int_0^{T_0} a_g(t) \cos \omega t dt \tag{2}$$

$$S(\omega) = \int_0^{T_0} a_g(t) \sin \omega t dt \tag{3}$$

The Fourier amplitude or spectral value can be calculated as:

$$FAS(\omega) = \sqrt{C^2(\omega) + S^2(\omega)} \tag{4}$$

Then, any desired number of peaks can be selected for modification of Inverse Fourier Transform of the acceleration record, as shown in Figure 1.

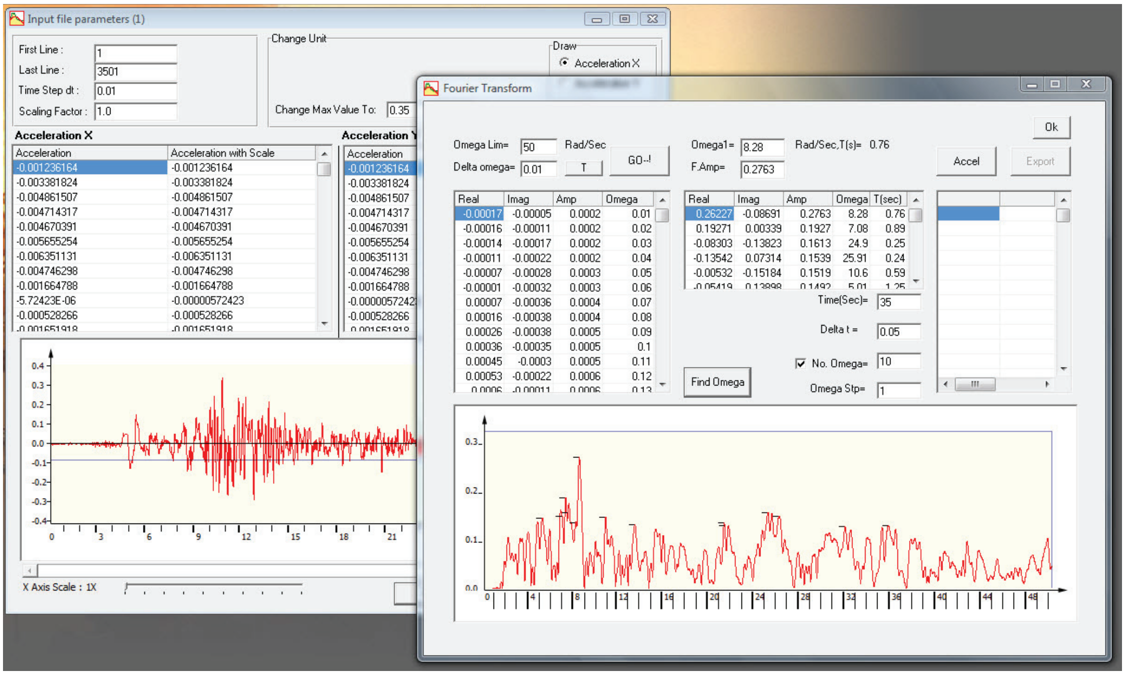


Figure 1- A screen view of the developed computer program for simplification of digitized accelerograms

The acceleration time history shown in Figure 1 along with its Fourier Transform is related to one of the recorded accelerograms of Tabas, Iran, earthquake of 1978, which has been digitized with a time step size of 0.01 sec. After selecting the desired number of peaks, which itself depends on the number of peaks which are close to the dominant natural frequencies of the structural system, an appropriate frequency band is considered for inclusion of frequencies around the peaks in the modified Inverse Fourier Transform of the record. Then, by choosing a larger time step such as 0.05 sec the modified Inverse Fourier Transform of the record is calculated, as shown in Figure 2.

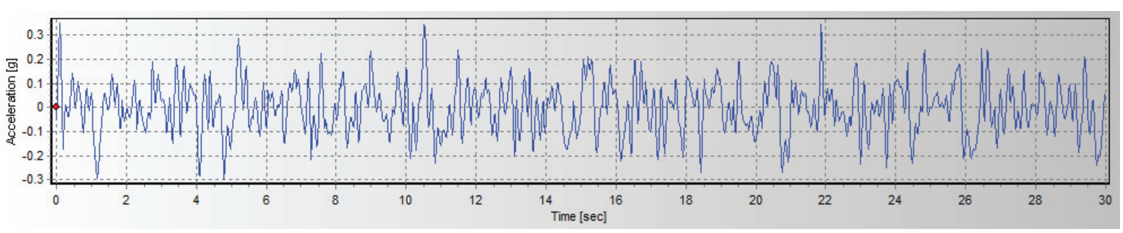


Figure 2- Simplified record of Tabas earthquake with larger time steps

Comparing Figures 1 and 2, it can be observed that the reproduced record is not similar to the original one. To find out whether this dissimilarity has any significant effect on the response values the response of a SDOF system with natural period of 0.3 sec have been calculated by both records, the results of which are shown in Figure 3.

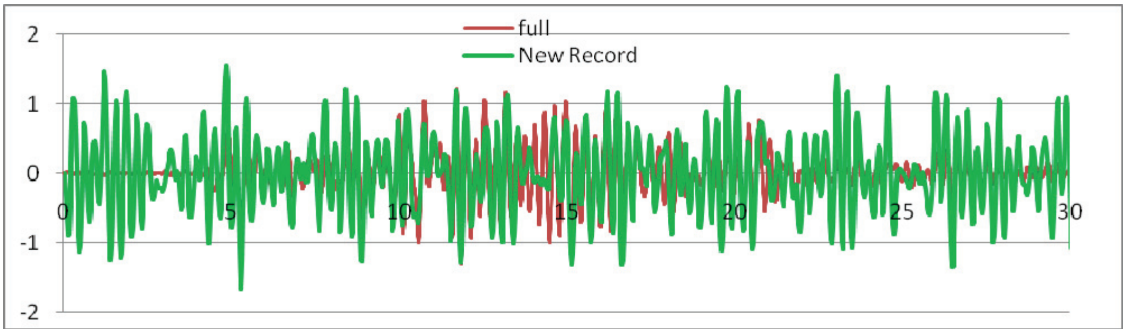


Figure 3- Response time histories of a SDOF system with natural period of 0.3 sec to original (full) and simplified (new) records of Tabas earthquake

It can be seen in Figure 3 that the two responses are not in good agreement. In fact, there is a difference of approximately 25 percent between the two peak responses and the instants of the peak responses are not the same. These differences can be due to either the deletion of some parts of the Fourier Spectrum or choosing a large time step for calculation of the Inverse Fourier Transform. To see which one of these two can be the main reason, it was decided to use the full Fourier Spectrum, and use just a large time step for calculating the Inverse Fourier Transform. The results of these calculations, using a time step size of 0.05 sec, which is ten times of the time step size of the original record (0.005 sec), can be seen in Figure 4, which relates to one of the accelerograms of Chi-Chi, Taiwan, earthquake of 1999.

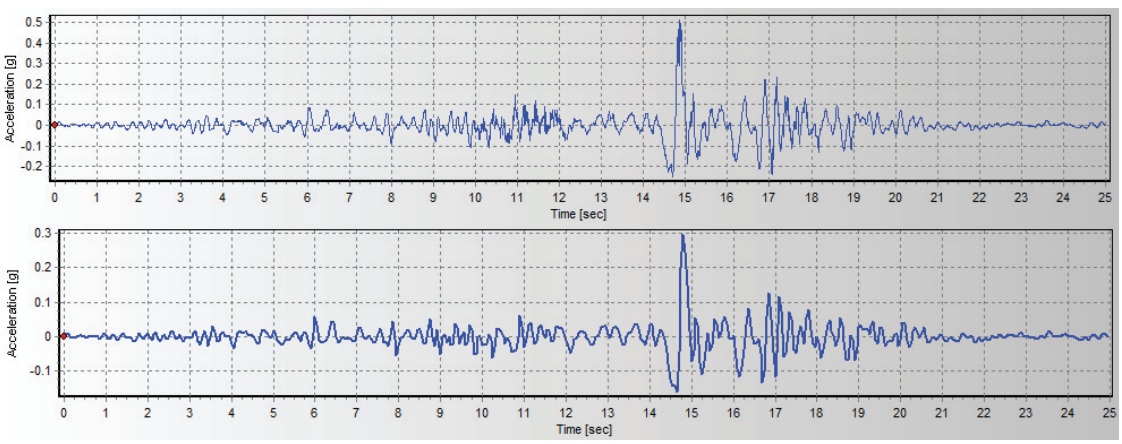


Figure 4- The original (up) and simplified (down) records of Chi-Chi, Taiwan earthquake

In Figure 4, it can be seen that the two records have very similar patterns, however, the simplified record has lower values. The reason behind this reduction is the use of larger time step size. However, the simplified record can be easily corrected by applying an appropriate scaling factor. To see whether the simplified record results in acceptable response values, the displacement and acceleration responses of some SDOF systems, having natural periods of 0.3, 0.5, 0.7, and 0.9 sec were calculated by both original and simplified records of Chi-Chi earthquake. The results related to the system with natural period of 0.3 sec are shown in Figure 5.

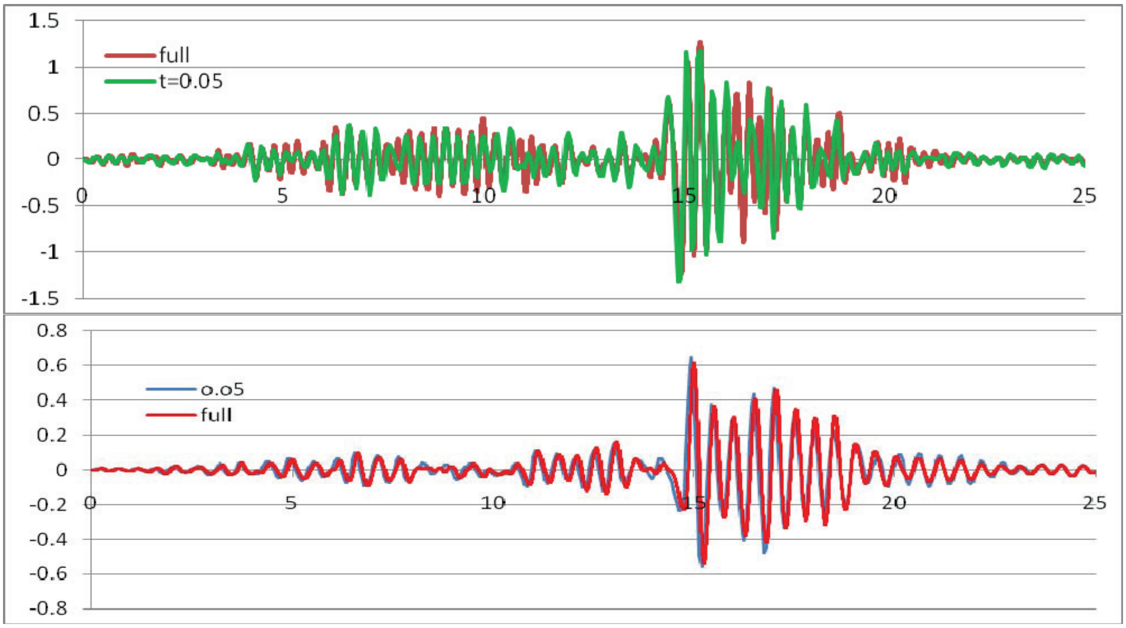
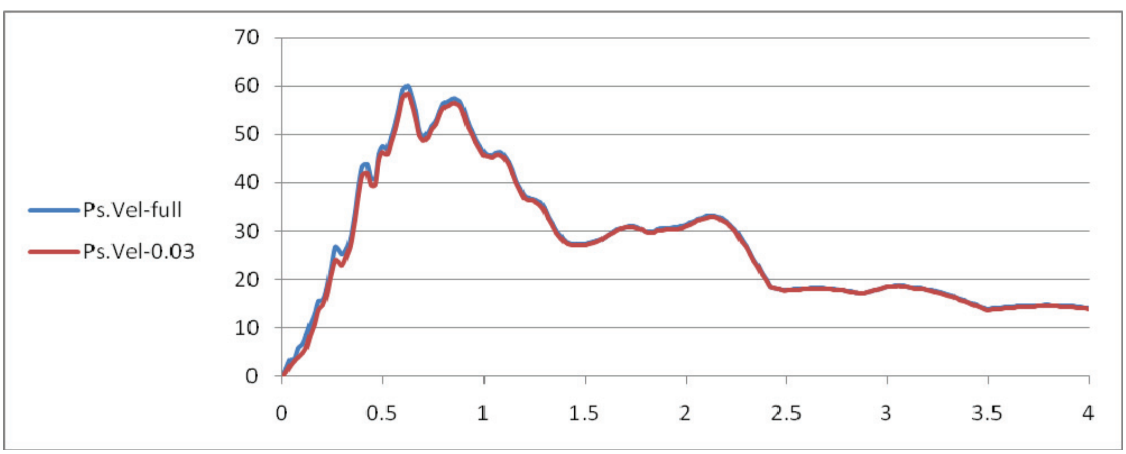


Figure 5- Displacement (up) and acceleration (down) responses of some SDOF systems, having natural period of 0.3 sec calculated by both original (shown in red) and simplified records of Chi-Chi earthquake

The good agreement of response values can be observed in Figure 5. Surprisingly, it is seen in figure that the agreement in case of acceleration responses is better than the case of displacement responses for the SDOF system with natural period of 0.3 sec, although, it can be mentioned that this is not true for SDOF systems with other values of natural period. However, a good agreement is observed between the response values obtained by the original and simplified accelerograms for other values of the system's natural period. There are more results of this type, obtained by employing the accelerograms of other earthquakes with various frequency contents from low to high, but can not be presented here due to the lack of space. To make sure that the agreement exists in the whole frequency range of the earthquakes, pseudo velocity and pseudo acceleration spectra of both original and simplified records were also calculated. Samples of these spectra are shown in Figure 6, which are related to the considered accelerogram of Chi-Chi earthquake and its simplified record using a time step size of 0.03 sec, which is 6 times of the time step size of the original record.



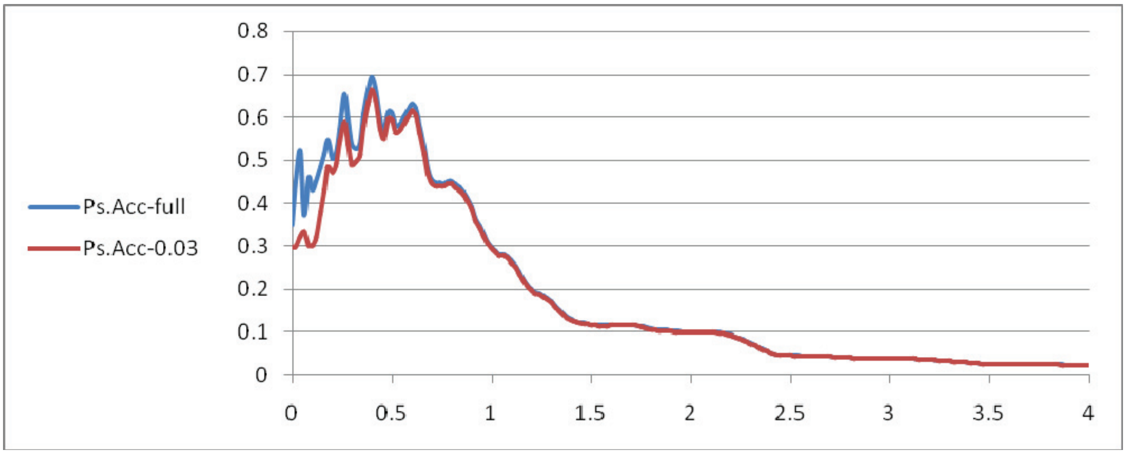


Figure 6- Pseudo velocity (up) and pseudo acceleration (down) spectra of the considered accelerogram of Chi-Chi earthquake calculated by both original (shown in blue) and simplified records, using a time step size of 0.03 sec (6 times of the original record)

It can be seen in Figure 6 that a very good agreement exists between the two pseudo velocity and pseudo acceleration spectra in almost the whole frequency range. As expected, in case of pseudo acceleration spectra the agreement is a little weak in the range of very lower periods, or higher frequencies.

4. CONCLUSIONS

Numerical results show that simplification of records by reproducing their Inverse Fourier Transform using a time step size of 5 to 10 times of that of the original records leads to only 5-10% error in the maximum values of displacement and acceleration responses, depending on the type of the structure and the features of the used records, while decreases the required response calculation time up to 10 times. With regard to response spectra, the simplified records leads to some reduction of the spectral acceleration values in lower period values, however the pseudo velocities of the original and the simplified records are in good agreement in the whole period range. Based on these results, it can be claimed that the proposed simplification technique is quite effective in reducing the computation costs.

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